Process Study of Oceanic Responses to Typhoons Using Arrays of EM-APEX Floats and Moorings

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LONG-TERM GOALS

Our long-term scientific goals are to understand the upper ocean dynamics, to understand the coupling between the ocean and atmosphere via air–sea fluxes, and to quantify the mechanisms of air–sea interactions. Our ultimate goal is to help develop improved parameterizations of air–sea fluxes in ocean–atmosphere models and parameterizations of small-scale processes in the upper ocean and the stratified interior.

OBJECTIVES

The energy of tropical cyclones is derived from the ocean via the air–sea flux. The oceanic heat content in the mixed layer and the air–sea enthalpy flux play important roles in determining the typhoon's maximum potential intensity, structure, energy, trajectory, and dynamic evolution. Forced by tropical cyclones, the most energetic oceanic processes are surface waves, wind-driven current, shear and turbulence, and inertial currents. To understand the dynamics and structures of tropical cyclones, one needs to understand these oceanic processes and quantify their effects on the air–sea flux during the passage of cyclones. Small-scale and meso-scale oceanic processes in the wake region also play crucial roles in determining the recovery of oceanic conditions after their responses to tropical cyclones. In tropical cyclones, these processes are the least understood primarily because of the paucity of direct field observations, consequently leading to large uncertainties in air–sea flux parameterizations.

For this project, we designed an experiment to make in-situ oceanic observations in the western Pacific on the paths of tropical cyclones to understand the coupled dynamics in a wide range of oceanic and

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atmospheric conditions. Our broad focus is on surface waves, inertial waves, shear instability, internal waves, and meso-scale eddies before, during, and after the tropical cyclones. Primary objectives of this project are (1) to provide observations of oceanic responses to a wide range of atmospheric wind forcing including tropical cyclones, (2) to provide observations of effects of oceanic conditions on the strength of tropical cyclones, and (3) to help provide better parameterization schemes for air–sea fluxes, especially in the tropical cyclone extreme wind forcing regime, and for interior ocean mixing.

APPROACH

We are making long-term mooring observations of atmosphere forcing and upper oceanic conditions in the western Pacific on the likely paths of tropical cyclones in 2009 and 2010. During the 2010 typhoon season, we will air-launch EM-APEX floats in front of typhoons. EM-APEX floats will transmit near-real time observations of velocity, temperature, salinity, and GPS position via Iridium satellite.

During the 2010 typhoon season (intensive observation period of ITOP), subsurface temperature measurements on the moorings will be transmitted via Iridium satellite and one upward-looking 75-kHz Long Ranger ADCP will be equipped on each of three moorings. All moorings will be recovered in October–November 2010.

WORK COMPLETED

Four ATLAS surface moorings (A1, A2, A3, and A4) and three subsurface moorings (SA1, SA2, and SA4) were deployed in the western Pacific Ocean before summer 2010. Locations of these moorings are shown in Table 1. Configurations of the surface and subsurface moorings are shown in Fig. 1. Each surface mooring is equipped with a series of more than 10 temperature sensors in the upper 500 m and a suite of meteorology sensors. Surface mooring meteorology measurements and subsurface temperature measurements are transmitted via Iridium satellite in near real-time and are published at http://140.112.68.246/~itop and http://kirin.apl.washington.edu/~itop.

Table 1. ITOP ATLAS mooring location and depth

Site	Lon	Lat	Lon	Lat	Type
A1	127.64°E	20.34 °N	127°38.24’ E	20°20.20’ N	Surface
A2	123.25 °E	21.07 °N	123°15.04' E	21°04.07' N	Surface
A3	126.06 °E	18.90 °N	126° 03.32’ E	18° 54.26’N	Surface
A4	123.84 °E	22.13 °N	123°50.09' E	22°07.54' N	Surface
SA1	127.53 °E	20.37°N	127°32.00’ E	20°22.46’ N	Subsurface
SA2	123.27 °E	21.23 °N	123°16.28’ E	21°13.94’ N	Subsurface
SA4	123.63 °E	22.00 °N	123°37.80’ E	22°00.24’ N	Subsurface

Fourteen EM-APEX floats are designated to be air-launched to western Pacific typhoons in the summer of 2010. Seven EM-APEX floats, together with Lagrangian floats and drifters, were air-launched in front of the typhoon Fanapi on 16 September 2010, separated by about 25 n mi. EM-APEX floats take measurements of temperature, salinity, pressure, and velocity. The data are transmitted via Iridium when the float surfaces. The remaining seven EM-APEX floats will be deployed in the next tropical storm.

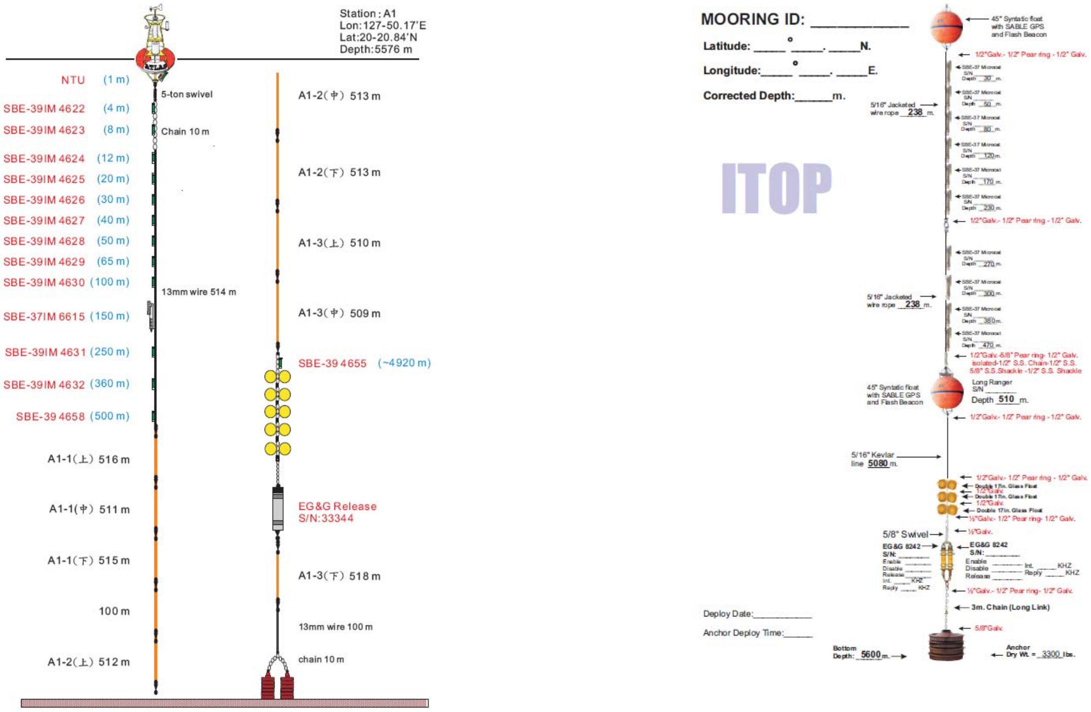

Figure 1. Schematic diagram of surface mooring (left panel) and subsurface mooring (right panel).

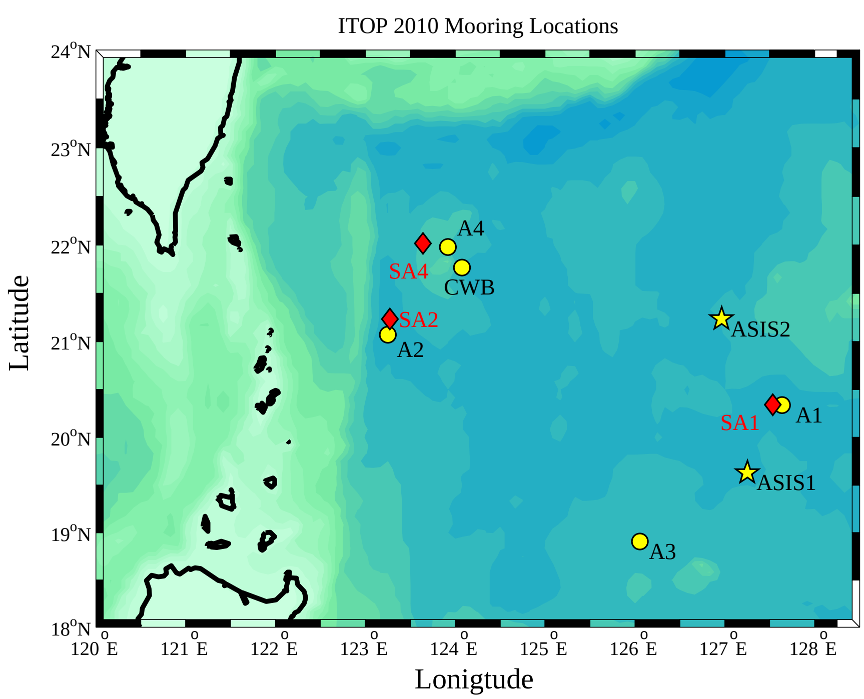

Figure 2. Locations of ITOP surface moorings (A1, A2, A3, and A4), and subsurface moorings (SA1, SA2, and SA4).

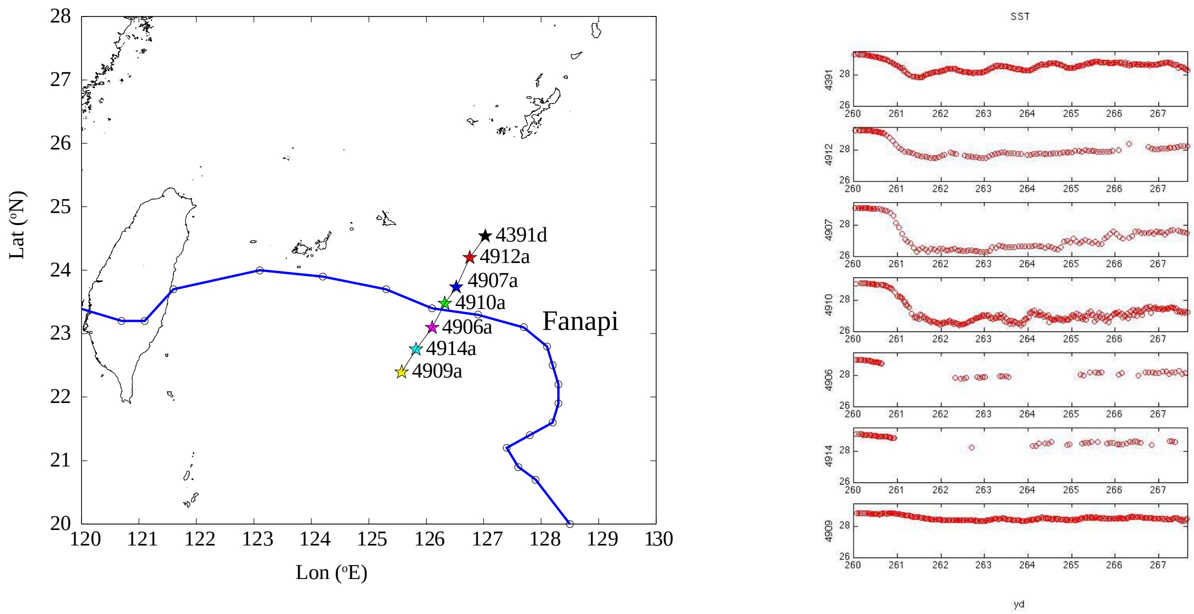

Figure 3. Left: Deployment of 7 EM-APEX floats (stars) ahead of typhoon Fanapi. The blue line shows the best track of typhoon Fanapi. Circles mark the positions at 6-hr intervals. Right: Average temperature in the upper 20 m.

RESULTS

ITOP Moorings

Several typhoons passed the ITOP mooring array in 2009. On 20 October 2009 the eye of typhoon Lupit passed the A1 mooring (Fig. 4). Within the eye, the air pressure dropped to 941 mb. The maximum wind speed reached ~120 kt. Within the eye, the wind was light, ~20 kt. A strong and rapid oceanic response was observed. The temperature in the upper ocean dropped by nearly 5°C. Strong upwelling and inertial responses were captured. Typhoon Lupit passed the A3 mooring later (Fig. 5). The minimum pressure recorded on A3 was 955 mb and the maximum wind 90 kt. As expected, to the left of the typhoon in the northern hemisphere, a weaker inertial response was observed. Surprisingly, stronger cooling, –6°C, was observed on the left side of typhoon (A3) compared to under the eye (A1).

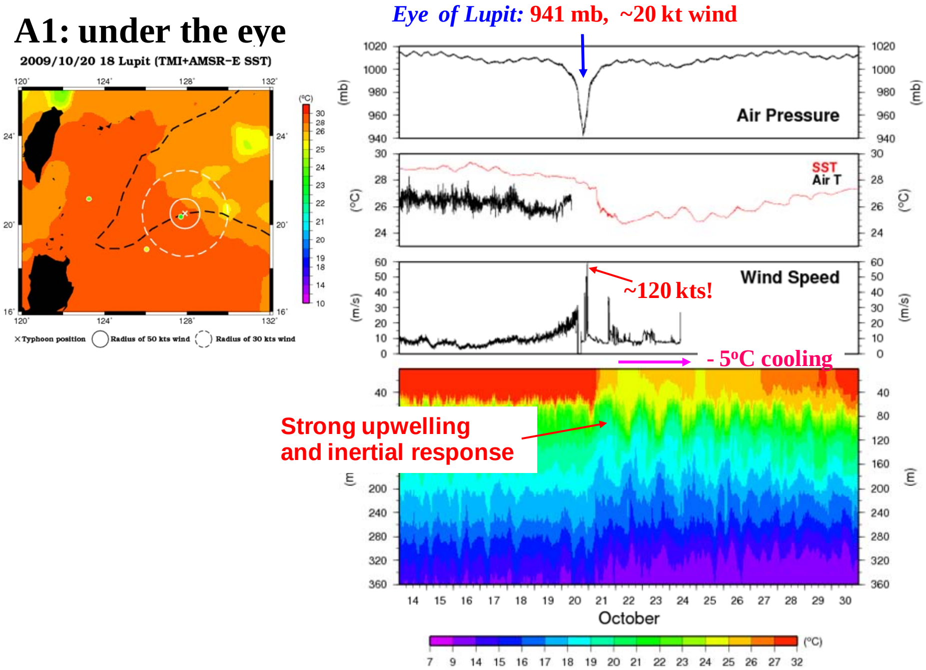

Figure 4. Measurements from the A1 mooring during the passage of typhoon Lupit.

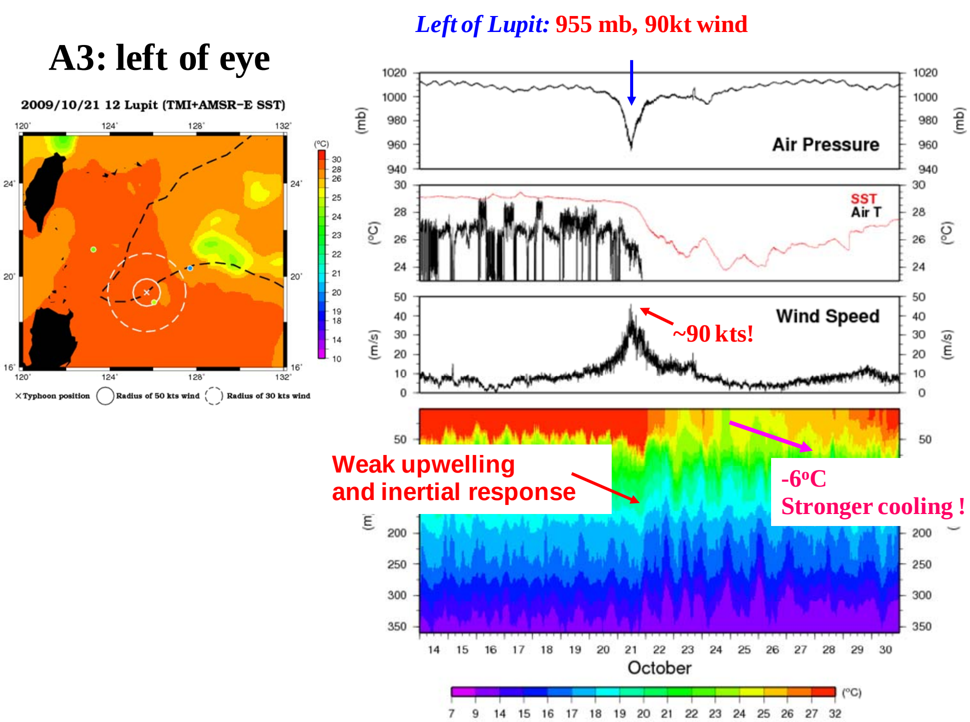

Figure 5. Measurements from the A3 mooring during the passage of typhoon Lupit.

IMPACT/APPLICATION

The oceanic heat content could significantly modulate the strength of the passing tropical cyclones. Similarly, tropical cyclones could cause strong oceanic responses, e.g., forcing surface waves, inertial waves, and deepening the surface mixed layer, etc. To improve the skill of modeling oceanic responses to tropical cyclones and the prediction of tropical cyclones, we need to understand the small-scale processes responsible for the air–sea fluxes and interior mixing, and the meso-scale oceanic processes that modulate the background oceanic heat content. The present field experiment will provide direct observations of oceanic responses forced by tropical cyclones and recovery after forcing, and aid in understanding the dynamics of small-scale and meso-scale oceanic processes. These observations will help improve the prediction skill of oceanic and atmospheric models in high wind regimes.

RELATED PROJECTS

Energy Budget of Nonlinear Internal Waves Near Dongsha (N00014-05-1-0284) as a part of NLIWI DRI: In this project, we study the dynamics and quantify the energy budget of nonlinear internal waves (NLIWs) in the South China Sea using observations taken from two intensive shipboard experiments in 2005 and 2007 and a set of nearly one-year velocity-profile measurements taken in 2006–2007 from four bottom mounted ADCPs across the continental slope east of Dongsha Plateau in the South China Sea. Results of NLIWI DRI will help improve our understanding of the dynamics of internal waves and their effects on the turbulence mixing in the upper ocean.

Study of Kuroshio Intrusion and Transport Using Moorings, HPIES, and EM-APEX Floats (N00014-08-1-0558) as a part of QPE DRI: The primary objectives of this observational program are 1) to quantify and to understand the dynamics of the Kuroshio intrusion and its migration into the southern East China Sea (SECS), 2) to identify the generation mechanisms of the Cold Dome often found on the SECS, 3) to quantify the internal tidal energy flux and budgets on the SECS and study the effects of the Kuroshio front on the internal tidal energy flux, 4) to quantify NLIWs and provide statistical properties of NLIWs on the SECS , and 5) to provide our results to acoustic investigators to assess the uncertainty of acoustic predictions. Results of this DRI program will help understand oceanic physical processes on the southern East China Sea, e.g., the cold dome. Typhoons may modulate the Kuroshio, the Kuroshio intrusion, and other oceanic processes that result in cold pools on the continental shelf of the southern East China Sea.

HONORS/AWARDS/PRIZES

Gledden Sr. Visiting Fellowship at University of Western Australia (Sanford, October 2008).